Total Effective Dose from INL Airborne Releases for Calculation of Population Dose for the 2020 CY ASER Report

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INTRODUCTION

Total effective radiation dose from airborne releases was calculated using air dispersion modeling performed by the National Oceanic and Atmospheric Administration (NOAA) Idaho Falls Office using their HYSPLIT computer model (Stein et al. 2015; Draxler et al. 2013), and the Dose Multi-Media (DOSEMM) dose assessment model version 190926 (Rood 2019). The DOSEMM documentation (Rood 2019) is for version 190429. The difference between the versions is that version 190926 has the option to use age-specific external dose coefficients from Federal Guidance Report 15 (EPA 2019). This option was not used in these runs so results between the two versions are identical. The objective of these calculations was to provide a grid of total effective dose across a model domain that encompasses a 50-mile (80-km) radius from any Idaho National Laboratory (INL) Site source. In addition to INL Site sources, releases from the Radiological and Environmental Sciences Laboratory (RESL) (Bldg IF-683), Bldg IF-611, and Bldg IF-603 located at the INL Research Center (IRC) within the Idaho Falls city limits were also included. These data are then used with GIS software to compute population dose. This report does not cover the population dose calculation and only documents generation of the gridded dose file.

MODEL DOMAIN AND HYSPLIT PROCESSING

The HYSPLIT model was used to calculate dispersion and deposition factors. Dispersion factors are defined as the monthly-average air concentration (g m^{-3}) divided by the release rate (g s^{-1}) and have units of s m^{-3}. Deposition factors are defined as the monthly-average deposition rate (g m^{-2} s^{-1}) divided by the release rate (g s^{-1}) and have units of m^{-2}. HYSPLIT model results were received from Bai Yang, NOAA Idaho Falls in NetCDF format. The modeling domain parameters are presented in Table 1. The 0.02-degree grid spacing equates to approximately 2 km. The files were first processed through the utility ncdump via the Perl script *runncdumpl.pl* that produced ASCII files of the gridded concentrations and deposition data (Appendix A) for each facility modeled.

Table 1. HYSPLIT modeling domain parameters

Parameter	Value
Model domain SW corner latitude (degrees)	42.6
Model domain SW corner longitude (degrees)	-114.76
Number of East-West nodes	177
Number of North-South nodes	101
Grid spacing (degrees)	0.02

Datum	WGS84
Grid center latitude (degrees)	43.6
Grid center longitude (degrees)	-112.9671
Top of ground-level cell	50 m above ground level

Separate NetCDF files were produced for each INL Site facility (e.g., INTEC, INTEC-MS, CFA, etc.) and IRC facilities (Table 2). Within each file, concentration data for three species were provided. Average monthly ground-level concentration output (in units of g m^{-3}) was provided in the variables con1, con2, and con3. The variable con1 was for concentration of a tracer (i.e., non-decaying non-depositing) gas. The variable con2 was for the concentration of a particulate with a dry deposition velocity of 0.0018 m s^{-1}, and the variable con3 was for the concentration of a reactive gas with a deposition velocity of 0.035 m s^{-1}. Monthly deposition output (in units of g m^2) was provided in the variable dep2 and dep3 corresponding to species 2 and 3. There was no deposition output for species 1. All concentration and deposition values were based on a constant source release rate of 1 g s^{-1}.

Table 2. Facilities modeled with HYSPLIT and release parameters. Only those facilities that had an appreciable dose were considered.

Facility	File Designation	Latitude and Longitude (degrees)	Release parameters
Reactor Test Area, Advanced Test Reactor (ATR) stack[a]	ATR_stack	43.589, -112.9671	Ht: 76.2 m, Stack dia: 1.524 m, Exit vel: 10.03 m/s, Temp: 293 K
Reactor test Area. Advanced Test Reactor, surface release	ATR_surface	43.5878, -112.9643	Ht: 0 m
Central Facilities Area (CFA)	CFA_surface	43.529, -112.9441	Ht: 0 m
Critical Infrastructure Test Range Complex (CITRC)	CITRC_surface	43.5504, -112.8593	Ht: 0 m
Idaho Nuclear Technology and Engineering Center (INTEC), main stack[b] (MS)	INTEC_stack	43.572, -112.9336	Ht: 76.2 m, Stack dia: 1.83 m, Exit vel: 10.65 m/s, Temp: 293 K
Idaho Nuclear Technology and Engineering Center	INTEC_surface	43.572, -112.9336	Ht: 0 m
Materials Fuels Complex (MFC)	MFC_surface	43.5951, -112.6567	Ht: 0 m
MFC, main stack and Transient Reactor Test Facility (TREAT) stack[c]	MFC_stack	43.5951, -112.6567	Ht: 60 m, Stack dia: 1.52 m, Exit vel: 9.081 m/s, Temp: 293 K
Naval Reactors Facility	NRF_surface	43.6489, -112.9162	Ht: 0 m
Radioactive Waste Management Complex (RWMC)	RWMC_surface	43.4999, -113.0407	Ht: 0 m
Radioactive Release Test Range (RRTR), Test Area North (TAN), and Special Materials Center (SMC)	RRTR_surface	43.8734, -112.725	Ht: 0 m
RESL, IF-683, IF-611, and IF-603[d]	RESL_surface	43.5159, -112.0348	Ht: 10 m, Exit Vel 0 m/s (no plume rise)

a. Releases from the MTR stack located at the ATR facility are modeled with this stack.
b. The stack exit velocity is based on earlier records. Stack velocity for 2019 was reported to be 3.59 m/s. Because the source is distant from the Maximally Exposed Individual (MEI) a rerun of HYSPLIT was not necessary.
c. Releases from the TREAT stack were modeled using the dispersion and deposition values from the MFC main stack. The TREAT stack diameter is 0.61 m resulting in higher stack velocity, greater plume rise, and greater dispersion. Thus, concentrations assuming the main stack for TREAT releases are overestimated.
d. All three sources are located at the INL Research Center and were assumed to be released from the RESL stack location.

SOURCE TERM

The radionuclide source term for facilities that contributed significantly to the annual dose was determined using CAP88 Version 4.0 (EPA 2013) modeling performed for the annual INL NESHAP[1] report for radionuclides. These sources and radionuclides were included in the HYSPLIT/DOSEMM modeling. Radionuclides that yielded greater than 0.1% of the total dose at the location of the maximally exposed individual (MEI) were selected (Table 3, Table 4, and Table 5). Additionally, radionuclides that contributed greater than 1% of a facility specific dose were included, with the exception of CIRTC because total dose from this facility was less than 0.000001% of the MEI dose. The MEI for 2020 was Receptor 54 near the INL east entrance. For the IRC sources in Idaho Falls, radionuclides that result in a dose greater than 0.1% of the total dose at the MEI in Idaho Falls were included (Table 6). Output from the CAP88 processing database was used for this task. Details are presented in Appendix B.

[1] The National Emission Standards for Hazardous Air Pollutants (NESHAPs) report for radionuclides is produced annually for all U.S. Department of Energy facilities that emit any radionuclides other than radon-222 and radon-220 into the air according to 40 CFR part 61, Subpart H.

Table 3. Particulate radionuclide source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.1% of the total dose for INL Site facilities at the MEI location.

Source	Am-241	Br-82	Cl-36	Co-60	Cs-137	Pu-238	Pu-239
CFA	4.04E-10			7.72E-11	3.46E-08		5.56E-09
CITRC							
INTEC	3.71E-06		7.14E-07	2.23E-06	3.13E-05	3.31E-06	2.47E-06
INTEC-MS	2.66E-13				5.99E-10	5.74E-12	9.81E-14
MFC	2.77E-11		7.19E-03	1.97E-12	2.61E-01	1.60E-08	2.41E-07
MFC-MS							1.82E-08
MFC-TREAT							5.47E-08
NRF				3.30E-06	7.80E-05		3.30E-06
RTC[a]	2.19E-05			7.65E-03	5.60E-03	4.06E-14	1.58E-08
RTC-ATR[a]	1.41E-07			1.13E-06	4.97E-05		
RTC-MTR[a]				1.11E-09	5.70E-11		
RWMC	7.24E-05			7.98E-16	7.98E-17	1.13E-06	2.58E-05
SMC		3.92E+00	1.04E-09				
TAN-TSF							
Total	9.81E-05	3.92E+00	7.19E-03	7.65E-03	2.67E-01	4.45E-06	3.19E-05

Source	Sr-90	Te-129m	U-234	U-235	U-238	Zn-65
CFA	1.14E-09	3.77E-14	7.45E-09	2.66E-10	3.82E-10	2.01E-12
CITRC						
INTEC	7.83E-06		1.57E-07	4.91E-09	1.07E-07	6.06E-17
INTEC-MS	5.49E-10					
MFC	1.72E-06	7.04E-01	6.46E-02	2.45E-03	1.09E-01	3.00E-01
MFC-MS	1.78E-07					
MFC-TREAT	1.62E-06					
NRF	5.60E-05					
RTC[a]	2.57E-02		2.64E-13	2.97E-10	8.01E-10	1.34E-05
RTC-ATR[a]						
RTC-MTR[a]			1.40E-10	1.02E-11	7.73E-10	9.45E-10
RWMC	2.29E-08			1.17E-10	9.50E-09	
SMC			1.52E-08	1.06E-09	8.45E-08	1.63E-08
TAN-TSF	1.02E-06					
Total	2.57E-02	7.04E-01	6.46E-02	2.45E-03	1.09E-01	3.00E-01

a. The Advanced Test Reactor Complex (ATRC) was formerly known as the Test Reactor Area (TRA) and Reactor Technology Complex (RTC). Acronyms based on former names may still be used to describe facility buildings, meteorological stations, etc.

Table 4. Noble gases source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.1% of the total dose for INL Site facilities at the MEI location.

Source	Ar-41	Kr-85m	Kr-87	Kr-88	Kr-89	Xe-138
CFA	2.00E-05		1.14E-06	7.94E-05		
CITRC						
INTEC						
INTEC-MS						
MFC						
MFC-MS						
MFC-TREAT	9.03E+01	1.12E+01	1.17E+01	1.06E+01	3.82E+01	1.81E+01
NRF						
RTC[a]	5.40E-05	9.60E-06	3.40E-05	1.14E-03		1.18E-04
RTC-ATR[a]	7.91E+02	7.18E+00	8.46E+00	3.16E+01		2.68E+01
RTC-MTR[a]						
RWMC						
SMC	3.32E-11		6.63E-21			
TAN-TSF						
Total	8.81E+01	1.84E+01	2.02E+01	4.22E+01	3.82E+01	4.49E+01

a. The Advanced Test Reactor Complex (ATRC) was formerly known as the Test Reactor Area (TRA) and Reactor Technology Complex (RTC). Acronyms based on former names may still be used to describe facility buildings, meteorological stations, etc.

Table 5. Iodine, C-14, and H-3 source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.1% of the total dose for INL Site facilities at the MEI location.

Source	I-129	I-131	C-14	H-3
CFA	2.76E-16	4.70E-10	2.00E-09	4.40E-01
CITRC				
INTEC	6.77E-05		2.76E-03	1.71E-01
INTEC-MS	3.92E-06			1.28E-03
MFC	4.87E-05	1.75E+00		4.22E-01
MFC-MS				
MFC-TREAT				
NRF	3.40E-05	5.70E-06	7.20E-01	1.30E-02
RTC[a]	3.92E-14	1.10E-06	4.32E-10	1.12E+02
RTC-ATR[a]		2.66E-07		2.73E+02
RTC-MTR[a]			1.35E-14	7.30E-01
RWMC			8.21E-02	5.14E+01
SMC				
TAN-TSF				3.26E-02
Total	1.54E-04	1.75E+00	8.05E-01	4.39E+02

a. The Advanced Test Reactor Complex (ATRC) was formerly known as the Test Reactor Area (TRA) and Reactor Technology Complex (RTC). Acronyms based on former names may still be used to describe facility buildings, meteorological stations, etc.

Table 6. Radionuclide source term (Ci yr^{-1}) for radionuclides that contributed greater than 0.1% of the total dose for INL facilities in Idaho Falls.

Radionuclide	IF-603	IF-611	IF-683 (RESL)	Total
Ac-227			5.57E-09	5.57E-09
Am-241			1.02E-07	1.02E-07
Am-243			1.04E-09	1.04E-09
Ba-133			3.83E-07	3.83E-07
Cs-134			2.50E-08	2.50E-08
Cs-137			7.34E-08	7.34E-08
Eu-152			4.73E-08	4.73E-08
Eu-154			8.32E-08	8.32E-08
I-125		1.00E-03	9.91E-08	1.00E-03
I-131			2.00E-07	2.00E-07
Np-237			6.48E-09	6.48E-09
Pa-231			1.15E-09	1.15E-09
Pu-238			7.90E-08	7.90E-08
Pu-239			1.32E-07	1.32E-07
Ra-226			7.53E-08	7.53E-08
Sr-90			7.21E-08	7.21E-08
U-232			3.21E-08	3.21E-08
U-233			1.64E-07	1.64E-07
Xe-133	5.10E-01	2.50E-05		5.10E-01

DOSEMM MODELING AND MODEL PARAMETERS

The DOSEMM model version 190926 (Rood 2019) was used to calculate total effective dose across the model domain for a fixed receptor scenario. DOSEMM reads the dispersion and deposition factors produced by HYSPLIT and the source term summarized in Table 3,

Table 5. Iodine, C-14, and H-3 source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.1% of the total dose for INL Site facilities at the MEI location.

Source	I-129	I-131	C-14	H-3
CFA	2.76E-16	4.70E-10	2.00E-09	4.40E-01
CITRC				
INTEC	6.77E-05		2.76E-03	1.71E-01
INTEC-MS	3.92E-06			1.28E-03
MFC	4.87E-05	1.75E+00		4.22E-01
MFC-MS				
MFC-TREAT				
NRF	3.40E-05	5.70E-06	7.20E-01	1.30E-02
RTC[a]	3.92E-14	1.10E-06	4.32E-10	1.12E+02
RTC-ATR[a]		2.66E-07		2.73E+02
RTC-MTR[a]			1.35E-14	7.30E-01
RWMC			8.21E-02	5.14E+01

Source	I-129	I-131	C-14	H-3
SMC				
TAN-TSF				3.26E-02
Total	1.54E-04	1.75E+00	8.05E-01	4.39E+02

b. The Advanced Test Reactor Complex (ATRC) was formerly known as the Test Reactor Area (TRA) and Reactor Technology Complex (RTC). Acronyms based on former names may still be used to describe facility buildings, meteorological stations, etc.

Table 6,

Table 5. Iodine, C-14, and H-3 source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.1% of the total dose for INL Site facilities at the MEI location.

Source	I-129	I-131	C-14	H-3
CFA	2.76E-16	4.70E-10	2.00E-09	4.40E-01
CITRC				
INTEC	6.77E-05		2.76E-03	1.71E-01
INTEC-MS	3.92E-06			1.28E-03
MFC	4.87E-05	1.75E+00		4.22E-01
MFC-MS				
MFC-TREAT				
NRF	3.40E-05	5.70E-06	7.20E-01	1.30E-02
RTC[a]	3.92E-14	1.10E-06	4.32E-10	1.12E+02
RTC-ATR[a]		2.66E-07		2.73E+02
RTC-MTR[a]			1.35E-14	7.30E-01
RWMC			8.21E-02	5.14E+01
SMC				
TAN-TSF				3.26E-02
Total	1.54E-04	1.75E+00	8.05E-01	4.39E+02

c. The Advanced Test Reactor Complex (ATRC) was formerly known as the Test Reactor Area (TRA) and Reactor Technology Complex (RTC). Acronyms based on former names may still be used to describe facility buildings, meteorological stations, etc.

Table 6, and Table 6. The dispersion and deposition factors and source term are used in combination with a food-chain and exposure model in DOSEMM to calculate radionuclide concentrations in air, soil, vegetables, meat, and milk, and calculate the associated doses from inhalation, ingestion, and external exposure. Nuclide independent parameters were taken from previous ASER spreadsheet calculations for assessment years 2015 and earlier (Table 7). DOSEMM uses a food-chain model similar to the ASER spreadsheet which is based on the CAP88 model (EPA 2013). Appendix B in Rood (2019) contains a benchmark comparison of the DOSEMM output and the ASER spreadsheet. Nuclide-independent parameters included the media intake rates and agriculture parameters.

Element-specific parameters include the linear sorption coefficient (K_d), plant and forage concentration ratios, and milk and meat transfer coefficients (Table 8). Carbon-14 and tritium are modeled using a specific-activity model and model parameters for these nuclides are presented in Table 9. Radionuclide-specific parameters (Table 10) include half-lives and dose coefficients for ingestion, inhalation, ground surface external exposure, and submersion in air. Exposure scenario parameters were taken from CAP88 version 4.0 and included inhalation and ingestion rates (Table 11). The NESHAP dose was computed using CAP88 version 4.0.

Table 7. Radionuclide independent parameters for DOSEMM modeling.

Variable	Value	Units	Description
V_d	0.0018	m s^{-1}	Deposition velocity for particulates
V_d	0.035	m s^{-1}	Deposition velocity for molecular iodine
DD1	0.50	---	Fraction of radioactivity retained on leafy vegetables and produce after washing.
FSUBG	1.00	---	Fraction of produce grown in garden of interest
FSUBL	1.00	---	Fraction of leafy vegetables grown in garden of interest
FSUBP	0.40	---	Fraction of year animals graze on pasture
FSUBS	0.43	---	Fraction of daily feed that is pasture grass when animal grazes on pasture
LAMW	0.0029	hr^{-1}	Removal rate for weathering from plants
P	215.00	kg m^{-2}	Effective surface density of soil
QSUBF	15.60	kg day^{-1}	Consumption rate of contaminated feed or forage by an animal (dry wt)
R_1	0.57		Fallout interception fraction (pasture)
R_2	0.2		Fallout interception fraction (vegetables)
TH_1	0.00	hr	Time delay-ingestion of pasture grass by animals
TH_2	2,160	hr	Time delay-ingestion of stored feed by animals
TH_3	336	hr	Time delay-ingestion of leafy vegetables by man
TH_4	336	hr	Time delay-ingestion of produce by man
TSUBB	876,000	hr	Buildup time in soil (hr) for food chain (100 yrs)
$TSUBE_1$	720	hr	Period of exposure (grassy pasture)
$TSUBE_2$	1,440	hr	Period of exposure (crops/leafy vegetables)
TSUBF	2.0	day	Transport time: animal feed-milk-man
TSUBS	20	day	Average time from slaughter of meat animal to consumption
VSUBM	11.0	liter day^{-1}	Milk production of cow
$YSUBV_1$	0.28	kg m^{-2}	Productivity: agriculture (grass-cow-milk-man pathway)
$YSUBV_2$	0.716	kg m^{-2}	Productivity: produce and vegetables (wet)

Table 8. Element-specific parameters for DOSEMM modeling (default values for RESRAD v7.2 Kamboj et al., 2018 except as noted).

Element	K_d (mL g^{-1})	Concentration Ratio vegetables	Concentration Ratio forage	Transfer Coefficient milk (L d^{-1})	Transfer Coefficient meat (kg d^{-1})
Ac	2.00E+01	2.50E-03	1.00E-01	2.00E-05	2.00E-05

Element	K_d (mL g^{-1})	Concentration Ratio vegetables	Concentration Ratio forage	Transfer Coefficient milk (L d^{-1})	Transfer Coefficient meat (kg d^{-1})
Am	2.00E+01	1.00E-03	1.00E-03	2.00E-06	5.00E-05
Ar	(a)	(a)	(a)	(a)	(a)
Ba	0.00E+00	5.00E-03	5.00E-03	5.00E-04	2.00E-04
Bi	0.00E+00	1.00E-01	1.00E-01	5.00E-04	2.00E-03
Br	1.00E-01	2.00E-02	2.00E-02	1.00E-02	7.00E-03
C	(b)	(b)	(b)	(b)	(b)
Cd	0.00E+00	3.00E-01	3.00E-01	1.00E-03	4.00E-04
Cl	0.00E+00	2.00E+01	2.00E+01	8.00E-02	6.00E-02
Co	1.00E+03	8.00E-02	8.00E-02	2.00E-03	2.00E-02
Cs	4.60E+03	4.00E-02	4.00E-02	8.00E-03	3.00E-02
Eu	3.40E+02	2.50E-03	2.50E-03	2.00E-05	2.00E-03
H	(b)	(b)	(b)	(b)	(b)
I	1.00E-01	2.00E-02	2.00E-02	1.00E-02	7.00E-03
Kr	(a)	(a)	(a)	(a)	(a)
Np[c]	8.00E+00	2.00E-02	2.00E-02	5.00E-06	1.00E-03
Pa	5.00E+01	2.50E-03	1.00E-01	5.00E-06	5.00E-03
Pb	1.00E+02	1.00E-02	1.00E-02	3.00E-04	8.00E-04
Po	1.00E+01	9.00E-03	1.00E-01	3.00E-04	5.00E-03
Pu	2.00E+03	1.00E-03	1.00E-03	1.00E-06	1.00E-04
Ra	7.00E+01	4.00E-02	4.00E-02	1.00E-03	1.00E-03
Rn	(a)	(a)	(a)	(a)	(a)
Sr	3.00E+01	3.00E-01	3.00E-01	2.00E-03	8.00E-03
Te	0.00E+00	6.00E-01	6.00E-01	5.00E-04	7.00E-03
Th	6.00E+04	1.00E-03	1.00E-03	5.00E-04	7.00E-03
U	5.00E+01	2.50E-03	2.50E-03	5.00E-04	7.00E-03
Y	0.00E+00	2.50E-03	2.50E-03	2.00E-05	2.00E-03
Xe	(a)	(a)	(a)	(a)	(a)
Zn	0.00E+00	4.00E-01	4.00E-01	1.00E-02	1.00E-01

a. Noble gases do not deposit and are not incorporated into food products
b. C-14 and H-3 are modeled using a specific activity model.
c. The K_d value for Np was the INL default value for INTEC modeling (Jenkins 2001) because RESRAD does not have a default value.

Table 9. Tritium and carbon-14 model parameters for DOSEMM modeling.

Parameter	Value	Reference
Absolute humidity (g m^{-3})	4.90	Till (1983)
Atmospheric concentration of carbon (g m^{-3})	0.18	Till (1983)
Fraction of vegetation that is water	0.824	Moore et al. (1979)
Fraction of vegetation that is carbon	0.339	Moore et al. (1979)
Fraction of beef that is water	0.623	Moore et al. (1979)
Fraction of milk that is water	1.0	NCRP (1996)
Fraction of beef that is carbon	0.23	NCRP (1996)
Fraction of milk that is carbon	0.169	Moore et al. (1979)

Table 10. Radionuclide half-lives and dose coefficients (DC) used in DOSEMM modeling.

Radionuclide	Inhalation Solubility Type[a,b]	Half-life (years)	Inhalation DC (rem Ci^{-1})[c]	Ingestion DC (rem Ci^{-1})[c]	Ground surface DC (rem-m^2 per Ci-s)[d]	Soil volume DC (rem-m^3 per Ci-s)[d]	Submersion DC (rem-m^3 per Ci-s)[c]
Ac-227	F	2.18E+01	5.96E+08	1.19E+06	3.64E-04	9.52E-06	1.35E-05
Am-241	M	4.32E+02	1.56E+08	7.55E+05	8.63E-05	7.36E-07	2.49E-03
Am-243	M	7.37E+03	1.54E+08	7.50E+05	7.49E-04	1.62E-05	7.10E-03
Ar-41	N/A	2.08E-04	0.00E+00	0.00E+00	4.50E-03	1.57E-04	2.28E-01
Ba-133	M	1.05E+01	1.36E+04	5.70E+03	1.38E-03	3.39E-05	6.00E-02
Br-82	M	4.03E-03	2.72E+03	2.03E+03	4.40E-03	3.06E-04	4.51E-01
C-14	M	5.73E+03	8.21E+03	2.15E+03	4.76E-08	2.18E-10	9.64E-06
Cd-115m	S	1.22E-01	3.15E+04	1.22E+04	3.42E-04	2.92E-06	7.36E-03
Cl-36	M	3.01E+05	2.98E+04	3.43E+03	4.14E-05	4.92E-08	6.14E-04
Co-60	M	5.27E+00	4.14E+04	1.26E+04	8.51E-03	3.05E-04	4.40E-01
Cs-134	F	2.06E+00	2.43E+04	7.13E+04	5.48E-03	1.56E-04	2.61E-01
Cs-137	F	3.01E+01	1.70E+04	5.02E+04	2.04E-03	6.34E-05	9.45E-02
Eu-152	F	1.35E+01	3.67E+05	4.96E+03	4.00E-03	1.13E-04	1.99E-01
Eu-154	F	8.59E+00	4.26E+05	7.29E+03	4.33E-03	1.24E-04	2.14E-01
H-3	W	1.23E+01	7.14E+01	7.09E+01	0.00E+00	0.00E+00	0.00E+00
I-125	F	1.63E-01	2.31E+04	5.74E+04	1.16E-04	2.36E-07	1.40E-03
I-129	F	1.57E+07	1.50E+05	4.00E+05	7.26E-05	1.90E-07	1.05E-03
I-131	F	2.20E-02	3.67E+04	8.05E+04	1.41E-03	4.04E-05	6.25E-02
Kr-88	N/A	3.24E-04	0.00E+00	0.00E+00	6.37E-03	2.50E-04	3.61E-01
Np-237	M	2.14E+06	8.51E+07	3.96E+05	9.32E-05	1.38E-06	3.18E-03
Pa-231	M	3.28E+04	3.52E+08	1.77E+06	1.40E-04	3.49E-06	5.36E-03
Pu-238	M	8.77E+01	1.72E+08	8.44E+05	2.32E-06	2.31E-09	1.24E-05
Pu-239	M	2.41E+04	1.86E+08	9.28E+05	1.05E-06	5.22E-09	1.39E-05
Ra-226	M	1.60E+03	1.41E+07	1.03E+06	6.24E-03	2.10E-04	1.15E-03
Sr-90	M	2.88E+01	1.45E+05	1.02E+05	4.12E-04	8.09E-07	3.65E-04
Te-129m	M	9.21E-02	2.69E+04	1.57E+04	4.77E-04	7.40E-06	1.28E-02

Table 10. Radionuclide half-lives and dose coefficients (DC) used in DOSEMM modeling.

Radionuclide	Inhalation Solubility Type[a,b]	Half-life (years)	Inhalation DC (rem Ci^{-1})[c]	Ingestion DC (rem Ci^{-1})[c]	Ground surface DC (rem-m^2 per Ci-s)[d]	Soil volume DC (rem-m^3 per Ci-s)[d]	Submersion DC (rem-m^3 per Ci-s)[c]
U-232	M	6.89E+01	3.19E+07	1.24E+06	2.99E-06	1.55E-08	4.00E-05
U-233	M	1.59E+05	1.44E+07	1.90E+05	2.22E-06	2.50E-08	3.92E-05
U-234	M	2.46E+05	1.41E+07	1.83E+05	2.17E-06	6.81E-09	2.27E-05
U-235	M	7.04E+08	1.25E+07	1.72E+05	5.18E-04	1.31E-05	2.54E-02
U-238	M	4.47E+09	1.16E+07	1.65E+05	4.29E-04	2.37E-06	1.18E-05
Xe-133	N/A	1.49E-02	0.00E+00	0.00E+00	1.47E-07	1.73E-06	5.07E-03
Xe-138	N/A	2.77E-05	0.00E+00	0.00E+00	1.23E-02	4.32E-04	6.27E-01
Zn-65	M	6.68E-01	6.66E+03	1.45E+04	2.00E-03	5.89E-05	1.01E-01

Notes: Ground surface and soil volume DCs include the following progeny (unless otherwise noted, the branching fraction is 1.0)
Ac-227 includes Th-227
Am-243 includes Np-239
Cs-137 includes Ba-137m, branching fraction 0.946 (also included in the submersion DC)
I-131 includes Xe-131m
Ra-226 includes Rn-222
Ra-226 includes Po-218
Ra-226 includes Pb-214
Ra-226 includes Bi-214
Ra-226 includes Po-214
Sr-90 includes Y-90
Te-129m includes Te-129, branching fraction 0.63 (also included in the submersion DC)
U-238 includes Th-234
U-238 includes Pa-234m
Xe-138 includes Cs-138 (also included in the submersion DC)

a. Solubility Types: S=slow, M=medium, F=fast, W=tritiated water, N/A= not applicable because inhalation DCs are zero.
b. Solubility types were the ICRP (2011) default if available. If a default solubility type was unavailable, then the ICRP solubility type for unspecified compounds was used, and if that was unavailable, then the highest dose coefficient was used.
c. DOE-STD-1196-2011 (DOE-2011)
d. FGR-13 (EPA 1999)

Table 11. Media intake rates for CAP88 Version 4.0.

Parameter	CAP88 version 4.0
Inhalation rate (m^3 yr^{-1})	5256
Leafy vegetable ingestion (kg yr^{-1})	7.79
Other vegetable ingestion (kg yr^{-1})	76.2
Meat ingestion (kg yr^{-1})	84
Milk ingestion (L yr^{-1})	53

RESULTS

The HYSPLIT/DOSEMM model was used to compute the effective dose at the MEI location and then calculate the dose at every grid node in the model domain for the MEI exposure scenario. Unlike years prior to 2019, the MEI was not at what is known as Frenchman's Cabin (located south of the INL at coordinates longitude -113.05666 and latitude 43.42690, UTM Zone 12 coordinates 333528E 4810276N) but at receptor 6 (see Figure 1) located south-southeast of the Materials Fuel

Complex (MFC) facility (-112.60029 longitude, 43.524604 latitude, UTM Zone 12 370677E 4820317N).

The dose at the MEI was 9.53E-03 mrem yr^{-1} and just slightly less than the 2019 dose of 9.95E-03 mrem yr^{-1}. The dose by pathway for INL Site sources (Table 12) was highest for the direct inhalation pathways followed by ingestion of other vegetables and beef. Particulate radionuclides had the highest contribution to the total dose. Dose by radionuclide at the INL Site MEI location (Table 13) were highest for U-238, I-131, U-234, Cs-137, and Cl-36. For comparison, the CAP88 version 4.0 doses at the MEI location are also shown in Table 13. The CAP88 total dose was a factor of 6.5 greater than the HYSPLIT/DOSEMM dose.

Table 12. Dose by pathway and radionuclide type at the INL Site MEI location for the HYSPLIT/DOSEMM model simulation for the 2020 ASER.

Pathway	Particulates (mrem yr^{-1})	Iodine (mrem yr^{-1})	Noble gas (mrem yr^{-1})	C-14, H-3 (mrem yr^{-1})	Total (mrem yr^{-1})
Inhalation, direct	3.50E-03	3.39E-05	0.00E+00	1.42E-06	3.53E-03
Inhalation, resuspension	3.37E-04	1.87E-05	0.00E+00	0.00E+00	3.56E-04
Ingestion, Leafy Veg	7.58E-05	7.66E-05	0.00E+00	4.69E-07	1.53E-04
Ingestion, Other Veg	8.25E-04	9.41E-04	0.00E+00	4.59E-06	1.77E-03
Ingestion Beef	1.60E-03	1.35E-04	0.00E+00	3.68E-06	1.74E-03
Ingestion Milk	3.66E-04	5.70E-04	0.00E+00	3.01E-06	9.38E-04
External, ground	3.43E-04	4.60E-04	0.00E+00	0.00E+00	8.03E-04
Submersion in air	1.13E-06	3.48E-07	2.34E-04	1.71E-12	2.36E-04
All Pathway	7.05E-03	2.24E-03	2.34E-04	1.32E-05	9.53E-03

Table 13. Dose by radionuclide at the INL Site MEI location for the HYSPLIT/DOSEMM and CAP88 version 4.0 model simulations for the 2020 ASER.

Radionuclide	DOSEMM Dose (mrem yr^{-1})	DOSEMM Fraction of Total	CAP88 Dose (mrem yr^{-1})	CAP88 Fraction of Total
Am-241	6.92E-07	0.01%	3.40E-05	0.06%
Br-82	7.94E-06	0.08%	1.37E-04	0.22%
Cl-36	7.72E-04	8.10%	3.59E-03	5.83%
Co-60	7.34E-07	0.01%	1.22E-04	0.20%
Cs-137	1.15E-03	12.10%	3.41E-02	55.31%
Pu-238	5.00E-08	0.00%	1.19E-06	0.00%
Pu-239	3.73E-07	0.00%	1.39E-05	0.02%
Sr-90	5.96E-06	0.06%	5.14E-04	0.83%
Te-129m	1.25E-04	1.31%	4.01E-04	0.65%
U-234	1.80E-03	18.86%	4.91E-03	7.97%
U-235	6.15E-05	0.64%	2.45E-04	0.40%
U-238	2.55E-03	26.72%	9.70E-03	15.75%
Zn-65	5.77E-04	6.05%	3.90E-03	6.33%
I-129	5.30E-06	0.06%	1.12E-05	0.02%
I-131	2.23E-03	23.40%	2.10E-03	3.41%
Ar-41	1.66E-04	1.74%	5.29E-04	0.86%
Kr-85m	2.49E-06	0.03%	8.60E-06	0.01%
Kr-88	3.47E-05	0.36%	1.50E-04	0.24%
Kr-89	3.42E-09	0.00%	8.79E-06	0.01%
Xe-138	3.13E-05	0.33%	5.38E-06	0.01%

Radionuclide	DOSEMM Dose (mrem yr^{-1})	DOSEMM Fraction of Total	CAP88 Dose (mrem yr^{-1})	CAP88 Fraction of Total
C-14	4.06E-06	0.04%	1.10E-04	0.18%
H-3	9.11E-06	0.10%	1.03E-03	1.67%
Total	9.53E-03	100.00%	6.16E-02	100.00%

The highest dose from IRC sources in Idaho Falls was calculated at a model node 1,500 m north of the RESL facility (longitude -112.03, latitude 43.53). The total dose was 1.80E-03 mrem/yr which is about factor of 5 lower than the dose for INL Site sources at the MEI location. Important radionuclides from the DOSEMM modeling for IRC facilities were I-125 (98.9%), Pu-239 (0.3%), Am-241 (0.2%), and Xe-133 (0.2%). The CAP88 dose for IRC facilities was 9.46E-3 mrem yr^{-1} which was a factor of 5.3 greater than that calculated by HYSPLIT/DOSEMM, but this value was calculated 115m south-southeast from the facility and a 1-m stack was assumed. The HYSPLIT grid resolution (about 2 km) was such that this receptor could not be represented and therefore the nearest node was selected.

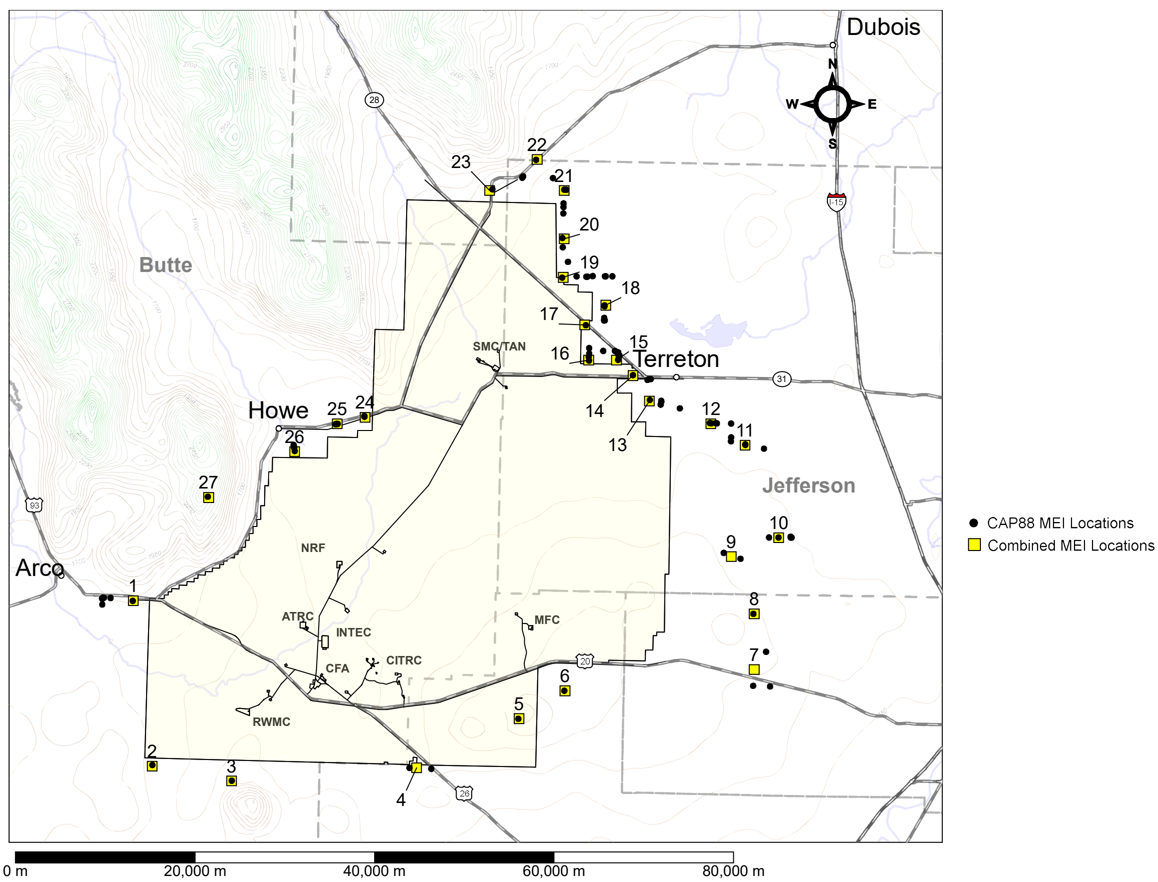

Figure 1. Maximally exposed individual locations surrounding the INL. The 27 locations (yellow circles) are a subset of 62 receptors (black dots) used in the CAP88 modeling. Locations that were close to one another were combined resulting in 27 unique locations.

Comparison with CAP88 Effective Dose at the INL Site MEI Location

CAP88 version 4.0 effective doses were calculated at receptor locations surrounding the INL Site that represent potential locations where a person might reside (Figure 1). The maximum effective dose for the MEI was calculated at receptor 6 in Figure 1. Receptor 6 corresponds to CAP88 receptor 54. The CAP88 version 4.0 MEI dose at receptor 6 was 6.16×10^{-2} mrem yr^{-1} whereas DOSEMM calculated a dose of 9.53×10^{-3} mrem yr^{-1} at this location. Doses were also calculated with DOSEMM for the list of 27 combined receptor locations illustrated in Figure 1 and the dose at the receptor 6 location was the highest which corresponds to the results from CAP88. The lower doses of the HYSPLIT/DOSEMM model are mostly attributed to the generally lower HYSPLIT dispersion factors compared to those from CAP88 which are shown in Table 14. Dispersion factors reflect differences in plume trajectory, turbulent diffusion, terrain complexities, plume depletion, and sector averaging between the HYSPLIT and CAP88 models. Only sources that contributed significantly to the dose were included in Table 14. These sources include MFC, MFC stacks, RTC, and RWMC. For iodine, the MFC source had HYSPLIT dispersion factors that were slightly higher than that of CAP88. For particulates, MFC HYSPLIT dispersion factors were a factor of 2.49 (stack releases) to 4.02 (surface releases) less than those from CAP88. More distant sources from the MEI (RWMC and ATR) showed greater divergence in dispersion factors from CAP88, mainly because CAP88 confines the plume to the sector width.

Table 14. Comparison of HYSPLIT and CAP88 X/Q values for 2020 ASER.

	DOSEMM average X/Q (s m^{-3})			CAP88 X/Q (s m^{-3})[a]			Ratio (CAP88/DOSEMM)		
Source	Particulate	Iodine	Gas	Particulate	Iodine	Gas	Particulate	Iodine	Gas
ATR	2.10E-10	5.00E-11	2.46E-10	7.69E-09	1.35E-10	2.22E-08	36.6	2.70	90.5
MFC	9.43E-09	3.18E-09	1.03E-08	3.96E-08	2.34E-09	1.04E-07	4.20	0.74	10.1
MFC-Stack	9.05E-09	3.76E-09	9.77E-09	2.25E-08	1.34E-08	2.35E-08	2.49	3.55	2.40
RWMC	3.03E-10	8.31E-11	3.03E-10	1.58E-08	2.53E-10	4.64E-08	52.0	3.04	153

a. Based on the X/Q value of U-234 for particulates, H-3 for gases, and I-129 for iodine

The total CAP88 dose was higher than the HYPLIT/DOSEMM dose by a factor of 6.5. In addition to the dispersion factors discussed earlier, CAP88 assumes a 100-year build up time in soil when computing external exposure whereas DOSEMM only includes the buildup that occurs for the source input time (i.e., 1-year). A 100-year buildup time is used in DOSEMM for accumulation of activity in vegetables, milk, and meat. Radionuclide buildup in surface soil for DOSEMM and CAP88 is given by

$$C = \frac{\psi}{k}\left(1 - e^{-kt}\right) \tag{1}$$

where

C = surface soil concentration (Ci m^{-2})

ψ = surface deposition rate (Ci m^{-2} s^{-1})

k = effective removal rate constant (s^{-1}).

The effective removal rate constant includes radioactive decay and leaching. Radionuclides with significant gamma exposure from deposition in the surface soil are Cs-137 and Co-60. These radionuclides have high sorption coefficients and thus loss by leaching is minimal. Assuming no leaching, the ratio of the Cs-137 surface concentration with 100-year buildup to that of 1-year buildup was 38.9 and 7.99 for Co-60. This difference accounts for the higher relative dose contribution from Cs-137 and Co-60 in CAP88 compared to DOSEMM.

Total Effective Dose Isopleth Map

Total effective dose isopleths across the model domain based on the MEI receptor scenario is illustrated in **Error! Reference source not found.**. The receptor 6 MEI location (in CAP88 this is receptor 54) is indicated by the blue star near the southern INL boundary and south of the MFC facility. The isopleths reflect the southwest to northeast prevailing winds at the INL and terrain features. An ASCII text file containing the effective dose by exposure pathway at each of the receptor nodes is provided in the file *EffectiveTotal.dat*. There is a small set of contours north of Idaho Falls that represent the dose from Idaho Falls facilities.

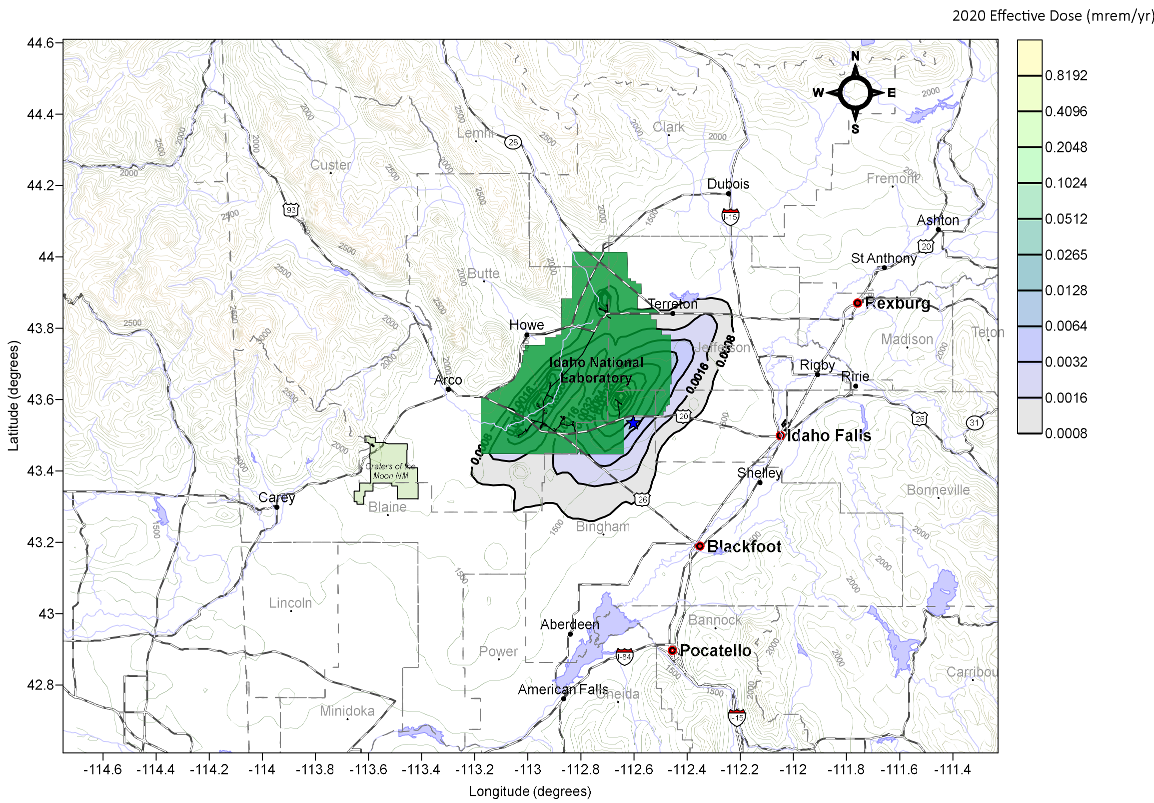

Figure 2. Isopleth map to total effective dose based on the MEI exposure scenario. The MEI at receptor 6 location is depicted as a blue star south of the INL southern boundary and near the MFC facility.

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APPENDIX A: PROCESSING INSTRUCTIONS FOR NETCDF FILES FROM NOAA HYSPLIT

1. NetCDF files will come in a separate zip file for each facility. Opening the zip file will create a new directory. There should be 12 files in each zip file comprising 12 months of data.

2. After extracting all the zip files in a directory for the give year (i.e. 2016files), run the runncdump.pl Perl script. You first have to modify the User input at the top of the script.

```
# runncdump.pl
# This script runs ncdump and extracts concentration and deposition varaibles for each
month and each facility
# Written by A.S. Rood, 06/19/17 for Wastren Inc

# ------------------------- User Input --------------------------------------
#@dirlst = ("ATR_surface_2016","CFA_surface_2016");

# enter the directory name for each source
@dirlst =
("ATR_stack_2016","INTEC_stack_2016","INTEC_surface_2016","MFC_stack_2016","NRF_surface_2
016","RWMC_surface_2016");

# ------------------------ End of User Input ---------------------------------

$ndir=$#dirlst;

for $i (0..$ndir)
{
   print "$dirlst[$i]\n";
   $cline=$dirlst[$i] . "/*.nc >junk";
   system "ls $cline";
   open(LST,"<junk");
   while ($line=<LST>)
   {
     chomp $line;
     $ofile=$line;
     $ofile =~ s/nc/asc/;
     $cline="ncdump -v con1,con2,con3,dep2,dep3 ".$line." >$ofile";
     print "$cline\n";
     system "$cline";
   }

}
```

3. The output files from ncdump are ASCII files that are then processed through ppnetcdf.f95. A separate parameter definition file is needed for each source. A sample parameter definition file is below.

```
INTEC_stack   5                                [srcname] [nvar]
con1,con2,con3,dep2,dep3              [varnames]
tracerxq,partxq,iodinexq,partpq,iodinepq      [specielist]
1  1  1  2  2                          [vtypeindx]
'../latlon.asc'                              [flatlon]
-1 -1 -1 -1                           [iminx][iminy[imaxx][imaxy]
12                                    [zone]
12                                    [nnetcdf]
Jan,Feb,Mar,Apr,May,Jun,Jul,Aug,Sep,Oct,Nov,Dec        [ncdfnames]
INTEC_stack_2018_01.asc                                [dfile]
INTEC_stack_2018_02.asc                                [dfile]
INTEC_stack_2018_03.asc                                [dfile]
INTEC_stack_2018_04.asc                                [dfile]
INTEC_stack_2018_05.asc                                [dfile]
```

```
INTEC_stack_2018_06.asc                              [dfile]
INTEC_stack_2018_07.asc                              [dfile]
INTEC_stack_2018_08.asc                              [dfile]
INTEC_stack_2018_09.asc                              [dfile]
INTEC_stack_2018_10.asc                              [dfile]
INTEC_stack_2018_11.asc                              [dfile]
INTEC_stack_2018_12.asc                              [dfile]
```

4. The file latlon.asc is produced from ncdump by

ncdump –v lat,lon [ncdumpfile] >latlon.asc

This file should be the same for all sources, and all remaining years provided the grid spacing and origins do not change. You will need the lat lon file before you run ppnetcdf.f95. A latlon file is below

```
netcdf ATR_stack_2018_01 {
dimensions:
        x = 177 ;
        y = 101 ;
variables:
        float lat(y) ;
                string lat:long_name = "Latitude of grid points" ;
                string lat:units = "deg N" ;
        float lon(x) ;
                string lon:long_name = "Longitude of grid points" ;
                string lon:units = "deg W" ;
        double xutm(x, y) ;
                string xutm:long_name = "UTM easting" ;
                string xutm:units = "m" ;
                xutm:zone = 12 ;
                string xutm:datum = "WGS84" ;
        double yutm(x, y) ;
                string yutm:long_name = "UTM northing" ;
                string yutm:units = "m" ;
                yutm:zone = 12 ;
                string yutm:datum = "WGS84" ;
        float con1(x, y) ;
                string con1:long_name = "Monthly average concentration species 1" ;
                string con1:units = "g m-3" ;
                con1:layer_bottom_m_agl = 0.f ;
                con1:layer_top_m_agl = 50.f ;
                string con1:deposition_vel = "0.0000 m/s" ;
                string con1:release_rate = "1.0 g/s" ;
        float con2(x, y) ;
                string con2:long_name = "Monthly average concentration species 2" ;
                string con2:units = "g m-3" ;
                con2:layer_bottom_m_agl = 0.f ;
                con2:layer_top_m_agl = 50.f ;
                string con2:deposition_vel = "0.0018 m/s" ;
                string con2:release_rate = "1.0 g/s" ;
        float con3(x, y) ;
                string con3:long_name = "Monthly average concentration species 3" ;
                string con3:units = "g m-3" ;
                con3:layer_bottom_m_agl = 0.f ;
                con3:layer_top_m_agl = 50.f ;
                string con3:deposition_vel = "0.0350 m/s" ;
                string con3:release_rate = "1.0 g/s" ;
        float dep2(x, y) ;
                string dep2:long_name = "Monthly average dry deposition species 2" ;
                string dep2:units = "g m-2" ;
                string dep2:deposition_vel = "0.0018 m/s" ;
```

```
                string dep2:release_rate = "1.0 g/s" ;
        float dep3(x, y) ;
                string dep3:long_name = "Monthly average dry deposition species 3" ;
                string dep3:units = "g m-2" ;
                string dep3:deposition_vel = "0.0350 m/s" ;
                string dep3:release_rate = "1.0 g/s" ;

// global attributes:
                string :description = "HYSPLIT monthly average concentration and
depositon" ;
                string :facility = "ATR" ;
                string :release_type = "stack" ;
                :source_lat = 43.589f ;
                :source_lon = -112.9671f ;
                :source_hgt_m_agl = 76.2f ;
                :model_top_m_msl = 6500. ;
                :grid_center_lat = 43.6f ;
                :grid_center_lon = -113.f ;
                :grid_spacing_lat = 0.02f ;
                :grid_spacing_lon = 0.02f ;
                string :release_start = "2016-12-31 0000 MST" ;
                string :release_end = "2017-02-01 0000 MST" ;
                string :averaging_start = "2017-01-01 0000 MST" ;
                string :averaging_end = "2017-02-01 0000 MST" ;
                :setup_cfg_rev = 6 ;
                :stack_dia_m = 1.524f ;
                :stack_exit_vel_ms = 10.03f ;
                :stack_exit_temp_K = 293.f ;
                string :contact = "Richard Eckman" ;
                string :email = "richard.eckman@noaa.gov" ;
                string :data_version = "1.0" ;
data:

 lat = 42.6, 42.62, 42.64, 42.66, 42.68, 42.7, 42.72, 42.74, 42.76, 42.78,
    42.8, 42.82, 42.84, 42.86, 42.88, 42.9, 42.92, 42.94, 42.96, 42.98, 43,
    43.02, 43.04, 43.06, 43.08, 43.1, 43.12, 43.14, 43.16, 43.18, 43.2,
    43.22, 43.24, 43.26, 43.28, 43.3, 43.32, 43.34, 43.36, 43.38, 43.4,
    43.42, 43.44, 43.46, 43.48, 43.5, 43.52, 43.54, 43.56, 43.58, 43.6,
    43.62, 43.64, 43.66, 43.68, 43.7, 43.72, 43.74, 43.76, 43.78, 43.8,
    43.82, 43.84, 43.86, 43.88, 43.9, 43.92, 43.94, 43.96, 43.98, 44, 44.02,
    44.04, 44.06, 44.08, 44.1, 44.12, 44.14, 44.16, 44.18, 44.2, 44.22,
    44.24, 44.26, 44.28, 44.3, 44.32, 44.34, 44.36, 44.38, 44.4, 44.42,
    44.44, 44.46, 44.48, 44.5, 44.52, 44.54, 44.56, 44.58, 44.6 ;

 lon = -114.76, -114.74, -114.72, -114.7, -114.68, -114.66, -114.64, -114.62,
    -114.6, -114.58, -114.56, -114.54, -114.52, -114.5, -114.48, -114.46,
    -114.44, -114.42, -114.4, -114.38, -114.36, -114.34, -114.32, -114.3,
    -114.28, -114.26, -114.24, -114.22, -114.2, -114.18, -114.16, -114.14,
    -114.12, -114.1, -114.08, -114.06, -114.04, -114.02, -114, -113.98,
    -113.96, -113.94, -113.92, -113.9, -113.88, -113.86, -113.84, -113.82,
    -113.8, -113.78, -113.76, -113.74, -113.72, -113.7, -113.68, -113.66,
    -113.64, -113.62, -113.6, -113.58, -113.56, -113.54, -113.52, -113.5,
    -113.48, -113.46, -113.44, -113.42, -113.4, -113.38, -113.36, -113.34,
    -113.32, -113.3, -113.28, -113.26, -113.24, -113.22, -113.2, -113.18,
    -113.16, -113.14, -113.12, -113.1, -113.08, -113.06, -113.04, -113.02,
    -113, -112.98, -112.96, -112.94, -112.92, -112.9, -112.88, -112.86,
    -112.84, -112.82, -112.8, -112.78, -112.76, -112.74, -112.72, -112.7,
    -112.68, -112.66, -112.64, -112.62, -112.6, -112.58, -112.56, -112.54,
    -112.52, -112.5, -112.48, -112.46, -112.44, -112.42, -112.4, -112.38,
    -112.36, -112.34, -112.32, -112.3, -112.28, -112.26, -112.24, -112.22,
    -112.2, -112.18, -112.16, -112.14, -112.12, -112.1, -112.08, -112.06,
    -112.04, -112.02, -112, -111.98, -111.96, -111.94, -111.92, -111.9,
    -111.88, -111.86, -111.84, -111.82, -111.8, -111.78, -111.76, -111.74,
    -111.72, -111.7, -111.68, -111.66, -111.64, -111.62, -111.6, -111.58,
    -111.56, -111.54, -111.52, -111.5, -111.48, -111.46, -111.44, -111.42,
    -111.4, -111.38, -111.36, -111.34, -111.32, -111.3, -111.28, -111.26,
    -111.24 ;
}
```

5. For each source, five output variables are stored in the ASCII netCDF file. con1, con2, con3, dep2, dep3

con1 is a conservative tracer and therefore has no corresponding deposition file. con2 and dep2 are X/Q and Psi/Q values for light particles and con3 and dep3 are X/Q and Psi/Q values for iodine. Deposition velocities are listed in the latlon.asc file.

Output from ppnetcdf.f95 contains the dosemm X/Q and Psi/Q files.

APPENDIX B: DEVELOPING SOURCE TERM FILES FOR DOSEMM ASER ASSESSMENT

In previous ASER reports the source term for DOSEMM was developed using the CAP88 database for NESHAPS using queries. The queries "DoseByFacilityNuclide" and "DoseByFacility" were run to derive the list of significant radionuclides and facilities that would be modeled. For the 2020 ASER, these queries were run by A.J. Sondrup of BEA and pasted into the spreadsheet "INL_2020_CAP88V4Results_5-24-21". Radionuclides that resulted in a dose greater than 0.1% of the total based on CAP88 modeling for 2020 were included in the DOSEMM assessment. These radionuclides are listed in the table below.

Nuclide	SumOfDose(mrem/yr)	% of Total	Cumulative %
Cs-137	3.39E-02	55.0%	55.0%
U-238	9.70E-03	15.7%	70.7%
U-234	4.91E-03	7.96%	78.7%
Zn-65	3.90E-03	6.32%	85.0%
Cl-36	3.59E-03	5.82%	90.8%
I-131	2.10E-03	3.408%	94.2%
Sr-90	5.13E-04	0.832%	95.1%
H-3	4.61E-04	0.747%	95.8%
H-3	4.47E-04	0.725%	96.5%
Ar-41	4.42E-04	0.717%	97.3%
Te-129m	4.01E-04	0.650%	97.9%
U-235	2.45E-04	0.397%	98.3%
Kr-88	1.38E-04	0.223%	98.5%
Br-82	1.37E-04	0.222%	98.7%
Cs-137	1.34E-04	0.218%	99.0%
Co-60	1.22E-04	0.198%	99.2%
H-3	1.09E-04	0.177%	99.3%
C-14	9.36E-05	0.152%	99.5%
Ar-41	8.70E-05	0.141%	99.6%

Additional nuclides were added based on nuclides that contributed greater than 1% of the total dose from each facility. Radionuclides from Idaho Falls facilities were provided in the spreadsheet IRC_2020_CAP88V4Results_5-13-21_AllReceptors and reproduced from the spreadsheet below.

Radionuclide	Dose (mrem/yr)	% of Total	Cumulative %
I-125	3.70E-03	39.14%	39.14%
Pu-239	1.58E-03	16.75%	55.89%
Xe-133	1.12E-03	11.87%	67.75%
Am-241	1.02E-03	10.79%	78.54%
Pu-238	8.69E-04	9.19%	87.73%
Ra-226	3.69E-04	3.90%	91.63%

U-233	1.28E-04	1.35%	92.99%
U-232	1.25E-04	1.32%	94.31%
Ac-227	1.00E-04	1.06%	95.37%
Cs-137	8.07E-05	0.85%	96.23%
Ba-133	7.28E-05	0.77%	97.00%
Sr-90	6.34E-05	0.67%	97.67%
Eu-154	4.24E-05	0.45%	98.12%
Np-237	3.89E-05	0.41%	98.53%
Eu-152	3.12E-05	0.33%	98.86%
Pa-231	2.76E-05	0.29%	99.15%
I-131	1.26E-05	0.13%	99.28%
Cs-134	1.25E-05	0.13%	99.41%
Am-243	1.04E-05	0.11%	99.52%

Radionuclides are assigned to these four classes:

PART – Particulates
I – Iodine
NG – noble gas
C14H3 – carbon-14 and tritium

The "DoseBySource&Facility" query produced the following results for the 2020 CAP88 run. Only those radionuclides that contributed greater than 0.1% of the total dose are included in the table below

Source	Facility	Dose (mrem/yr)	% of Total	Cumulative %
MFC-1702-001	MFC	3.40E-02	55.0%	55.0%
MFC-784-001	MFC	1.49E-02	24.1%	79.1%
MFC-774-027	MFC	2.50E-03	4.06%	83.2%
MFC-774-028	MFC	2.50E-03	4.06%	87.2%
MFC-774-029	MFC	2.50E-03	4.06%	91.3%
MFC-774-026	MFC	2.50E-03	4.06%	95.3%
TRA-715-001	RTC	1.23E-03	2.00%	97.3%
MFC-720-007	MFC-TREAT	6.71E-04	1.09%	98.4%
Beryllium-Blocks	RWMC	4.52E-04	0.732%	99.2%
TRA-770-001	RTC-ATR	2.11E-04	0.343%	99.5%
RRTR-North	SMC	1.38E-04	0.223%	99.7%
NRF	NRF	9.55E-05	0.155%	99.9%

For the 2020 DOSEMM run, all facilities were included in the simulation regardless of contribution with the exception of CITRC, which had doses substantially lower than any of the other facilities. In ASERs prior to 2019, a query was used to extract the important radionuclides from the database. The output was pasted in a spreadsheet and rearranged into the DOSEMM format. For the 2019 and newer ASER calculations, a Perl script was written where the input to the script is the radionuclide release rates for each facility. The radionuclide release rates by source and facility were provided in the spreadsheet "2020 NESHAPv4 Sources Tracking List_5-24-21.xlsx" on the sheet "releases INL_import_to_db_ready" for INL Site facilities and "releases

IRC_import_to_db_ready" for Idaho Falls facilities. The data on each of these sheets was imported to a database (SourceTerm2020.accdb) and queries were written that summed the radionuclide release rates across the sources for each facility. The output from these queries were then exported to a text file that contained the fields "Facility", "Radionuclide", and "Q" (release rate in Ci/yr) ("2020SourceTerm.txt"). The SQL for the INL Site query is

```
SELECT [releases INL import to db_ready].FacilityID, [releases INL import to db_ready].Radionuclide, Sum([releases INL import to db_ready].[Q-CiperYear]) AS [SumOfQ-CiperYear]
FROM [releases INL import to db_ready] INNER JOIN [INL Nuclide List] ON [releases INL import to db_ready].Radionuclide = [INL Nuclide List].Radionuclide
GROUP BY [releases INL import to db_ready].FacilityID, [releases INL import to db_ready].Radionuclide;
```

The query for the IRC facilities has a similar form. The first few records of the text file for the INL Site are provided below.

```
FacilityID  Radionuclide    SumOfQ-Ci/Year
CFA     Am-241  4.040E-10
CFA     Ar-41   2.000E-05
CFA     C-14    2.000E-09
CFA     Co-60   7.720E-11
CFA     Cs-137  3.460E-08
CFA     H-3     4.400E-01
CFA     I-129   2.760E-16
CFA     I-131   4.700E-10
CFA     Kr-87   1.140E-06
CFA     Kr-88   7.940E-05
CFA     Pu-239  5.560E-09
CFA     Sr-90   1.140E-09
.........
```

The Perl script then uses the information in the header portion of the script to extract the important radionuclides and write DOSEMM compatible files. For some sources such as MFC stack releases and releases from TAN and SMC, the same X/Q value is used. In these cases, the release quantities may be summed into one release file within the script. Alternatively, each source may be run separately. The Perl script is below.

```
# mkSourceTerm.pl
# This script makes the dosemm source term files from a datatabase printout of the entre source term
# ------------- User Input ----------------

# The sourcein array are the names of the sources provided in the CAP88 DB
      @sourcein =("IF-603","IF-611","IF-638","RESL_IF-683");                # IRC sources
#          @sourcein  =("CFA","CITRC","INTEC","INTEC-MS","MFC","MFC-MS","MFC-TREAT","NRF","RTC","RTC-ATR","RTC-MTR","RWMC","SMC","TAN-TSF");  # INL sourcs

# The sourceout array are the sources in the same order, renamed (if applicable) that will be provided to dosemm
       @sourceout = ("IRC");              # IRC sources
#                 @sourceout   =   ("CFA","CITRC","INTEC","INTEC-MS","MFC","MFC-MS","NRF","RTC","RTC-ATR","RTC-MTR","RWMC","SMC");


# The srcinclude array indicates what sources to add to one another. 0 = add no sources, 1=add the next source, 2=add the next two sources etc.
      @srcinclude = (3);              # IRC sources
#      @srcinclude = (0,    0,          0,       0,      0,     1,     0,      0,     0,       0,     0,    1);
# INL sources
# input File
      $filein="2020SourceTermIRC.txt";
#      $filein="2020SourceTerm.txt";

# Suffix contcatenated with sources files by effluent type
      @types = ("-PART.rel","-I.rel","-NG.rel","-C14H3.rel");
```

```
#      @types = ("-PART2.rel");
# radionuclides in each type - MUST be in the same order that are in the release files
#     @particle = ("Am-241","Br-82","Cl-36","Cs-137","Pu-238","Pu-239","Sr-90","U-234","U-238","Zn-65");   # INL
radionuclides
#     @particle = ("Co-60","Te-129m","U-235");   # additional INL radionuclides

# particulate radionuclides for IRC sources run 1
      @particle = ("Ac-227","Am-241","Am-243","Ba-133","Cs-134","Cs-137","Eu-152","Eu-154");
# particulate radionuclides for IRC sources run 2
#      @particle = ("Np-237","Pa-231","Pu-238","Pu-239","Ra-226","Sr-90","U-232","U-233");

      @iodine = ("I-129","I-131");   # INL
      @ngas = ("Ar-41","Kr-85m","Kr-87","Kr-88","Kr-89","Xe-138");  #INL
      @c14h3 = ("C-14","H-3"); #INL

      @iodine = ("I-125","I-131");   # IRC
      @ngas = ("Xe-133");  #IRC
      @c14h3 = (); #IRC

      $year="2020";
# ------------- End of User Input ----------------
     $nsrcin=$#sourcein;
     $nsrcout=$#sourceout;
     %srctermin=0.;
# ------------ Read db file ---------------------
     open(IN,"<$filein");
     $line=<IN>;
     while($line=<IN>)
     {
        chop $line;                          # remove return
#        $line =~ s/^[ ]+//;                  # delete initial spaces
        @field = split /[ ,]+/, $line;      # split into fields with space or comma delimiter
        print "$field[0],$field[1],$field[2]  ";
        $stermin{$field[0]}{$field[1]}=$field[2]/3.1536E7;             # convert from Ci/yr to Ci/s
        print "$field[0] $field[1] $stermin{$field[0]}{$field[1]}\n";
     }
     close IN;

# ------ Loop to write release files --------------------

     for $i (0..$#sourceout)
     {
#  particulates
          $fileout=$sourceout[$i] . $types[0];
          open(OUT,">$fileout");
          print OUT "Year  Month ";
          for $j (0..$#particle) {printf OUT "%-11s",$particle[$j]}
          print OUT "  Ci/s Sources: ";
          $ii=getindx();

          print "$i  $ii\n";
          for $m (0..$srcinclude[$i])
          {
                 print OUT "$sourcein[$ii] ";
                 $ii=$ii+1;
          }
          print OUT "\n";

          for $k (1..12)
          {
                 printf OUT "%-4d  %-2d   ",$year,$k;
                 for $j (0..$#particle)
                 {
                     $val=0;
                     $ii=getindx();
                     for $m (0..$srcinclude[$i])
                     {
                            #print "$sourceout[$i]  $stermin{$sourcein[$ii]}{$particle[$j]}\n";
                            $val=$val+$stermin{$sourcein[$ii]}{$particle[$j]};
                            $ii=$ii+1;
                     }
                     printf OUT " %-10.3e",$val;
                 }
                 print OUT "\n";
          }
          close OUT;

#  iodine
          $fileout=$sourceout[$i] . $types[1];
          open(OUT,">$fileout");
          print OUT "Year  Month ";
          for $j (0..$#iodine) {printf OUT "%-11s",$iodine[$j]}
          print OUT "  Ci/s Sources: ";
          $ii=getindx();
          for $m (0..$srcinclude[$i])
          {
                 print OUT "$sourcein[$ii] ";
```

```
                $ii=$ii+1;
        }
        print OUT "\n";

        for $k (1..12)
        {
                printf OUT "%-4d  %-2d   ",$year,$k;
                for $j (0..$#iodine)
                {
                    $val=0;
                    $ii=getindx();
                    for $m (0..$srcinclude[$i])
                    {
                           #print "$sourceout[$i]  $stermin{$sourcein[$ii]}{$particle[$j]}\n";
                           $val=$val+$stermin{$sourcein[$ii]}{$iodine[$j]};
                           $ii=$ii+1;
                    }
                    printf OUT " %-10.3e",$val;
                }
                print OUT "\n";
        }
        close OUT;

#  ngas
        $fileout=$sourceout[$i] . $types[2];
        open(OUT,">$fileout");
        print OUT "Year  Month ";
        for $j (0..$#ngas) {printf OUT "%-11s",$ngas[$j]}
        print OUT "  Ci/s Sources: ";
        $ii=getindx();
        for $m (0..$srcinclude[$i])
        {
                print OUT "$sourcein[$ii] ";
                $ii=$ii+1;
        }
        print OUT "\n";

        for $k (1..12)
        {
                printf OUT "%-4d  %-2d   ",$year,$k;
                for $j (0..$#ngas)
                {
                    $val=0;
                    $ii=getindx();
                    for $m (0..$srcinclude[$i])
                    {
                           #print "$sourceout[$i]  $stermin{$sourcein[$ii]}{$particle[$j]}\n";
                           $val=$val+$stermin{$sourcein[$ii]}{$ngas[$j]};
                           $ii=$ii+1;
                    }
                    printf OUT " %-10.3e",$val;
                }
                print OUT "\n";
        }
        close OUT;

#  c14 and h3
        $fileout=$sourceout[$i] . $types[3];
        open(OUT,">$fileout");
        print OUT "Year  Month ";
        for $j (0..$#c14h3) {printf OUT "%-11s",$c14h3[$j]}
        print OUT "  Ci/s Sources:";
        $ii=getindx();
        for $m (0..$srcinclude[$i])
        {
                print OUT "$sourcein[$ii] ";
                $ii=$ii+1;
        }
        print OUT "\n";

        for $k (1..12)
        {
                printf OUT "%-4d  %-2d   ",$year,$k;
                for $j (0..$#c14h3)
                {
                    $val=0;
                    $ii=getindx();
                    for $m (0..$srcinclude[$i])
                    {
                           #print "$sourceout[$i]  $stermin{$sourcein[$ii]}{$particle[$j]}\n";
                           $val=$val+$stermin{$sourcein[$ii]}{$c14h3[$j]};
                           $ii=$ii+1;
                    }
                    printf OUT " %-10.3e",$val;
                }
```

```
            print OUT "\n";
        }
        close OUT;
}

sub getindx()
{
  if($i>0)
  {
    $kk=0;
    for $j (1..$i)
    {
      $kk=$kk+1+$srcinclude[$j-1];
    }
  }
  else {$kk=0;}
  return $kk;

}
```

The script produces a DOSEMM release file. The release file for noble gases from a single source (the MFC stack) is provided below. In the case of MFC stacks where releases from the main stack and the TREAT stack are combined, the release file documents the sources that are included in the release rates.

```
Year  Month Ar-41      Kr-85m     Kr-87      Kr-88      Kr-89      Xe-138      Ci/s Sources:
MFC-MS MFC-TREAT
2020  1     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  2     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  3     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  4     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  5     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  6     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  7     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  8     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  9     2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  10    2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  11    2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
2020  12    2.863e-06  3.551e-07  3.710e-07  3.361e-07  1.211e-06  5.739e-07
```

The remainder of the release files along with all other input and output files are provided in the electronic distribution.